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THE RELATION OF PLANT SOCIETIES TO EVAPORATION

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(WITH NINE FIGURES)

During the summers of 1906 and 1907 the writer made a study of the plant societies about Cold Spring Harbor, Long Island, N. Y. In this connection an effort was made to obtain quantitative measurements of the various environmental factors upon which depend habitat differentiation and the succession of plant societies. The publication of LIVINGSTON'S paper on "The relation of desert plants to soil moisture and to evaporation" in the autumn of 1906 suggested to me that a series of vaporimeters, standardized and exposed in the various plant societies, would give comparative data that would be far more valuable than the usual temperature and relative humidity readings.

Through the kindness of DR. LIVINGSTON I was supplied with several porous cups which were standardized with the vaporimeter at Tucson. They were similar to those afterward sent out from the Desert Laboratory to various parts of the United States. For this reason the readings given in this paper may be compared directly with any obtained by other observers using these instruments.

In the nature of the case, with the small number of instruments at my disposal, it became necessary to establish one instrument as a standard for the region. Because of the desirability of having a record of the rate of evaporation in the garden of the Station for Experimental Evolution, the standard vaporimeter for my work was placed in this garden about 3^{m} east of the weather bureau instrument shelter. With this instrument all others were compared. Whenever a vaporimeter was placed in a habitat, or a reading made, a corre-

sponding reading was made of the standard vaporimeter, as nearly simultaneously as possible (*fig. 1*).

The vaporimeter consists of a porous cup supported about 1^{dm} above a pint jar by a glass tube which extends from the upper end of

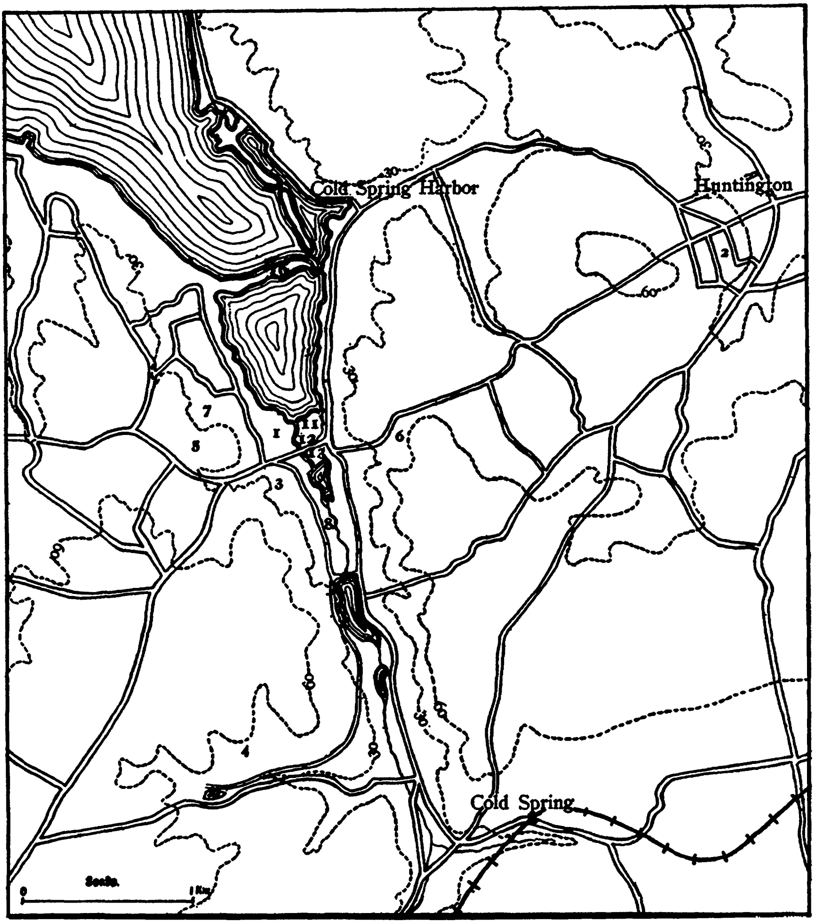

FIG. 1.—Sketch map showing positions of all stations except Station 9. Contour interval 30^{m}.

the porous cup to the bottom of the jar. The tube is fitted air tight into the porous cup by a rubber stopper. The top of the jar is covered by a cork which is nearly air tight. Surrounding the tube above the jar is a conical shield of paraffined cloth to keep out rain. In use the jar was sunk in the ground to within 2^{cm} of the top. In setting up

the instrument, the porous cup and tube were completely filled with water and the jar was filled to a mark near the top. At convenient intervals the loss of water by evaporation was determined by running in water from a burette and restoring the original water level. Because of the large water area in the jar the error in these readings is estimated to be $\pm 1^{cc}$.

Following are the vaporimeter readings for the several habitats, with their accompanying vegetation. The corresponding record for the standard instrument is given in each case, together with the comparative evaporation expressed in percentages of the standard.

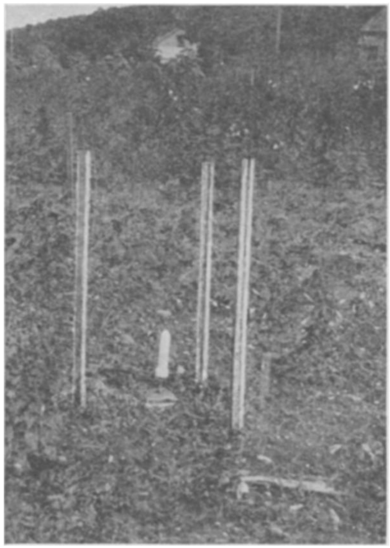

FIG. 2.—Standard instrument in position.

Station 1 (standard).—Located in the east plot of the garden of the Station for Experimental Evolution; altitude above sea-level about 3^{m}. During the summer the area adjacent to the vaporimeter was occupied by plants of *Oenothera nanella*, set 1^{m} from the instrument and from each other. The small size of this variety of evening primrose left the instrument freely exposed to the sun and air. The soil is a dark-colored sandy loam (*figs. 2, 3*).

AMOUNT OF EVAPORATION BY WEEKS

Week ending	May 27, 197^{cc}	Week ending	July 8, 152^{cc}
" "	June 3, 106	" "	July 15, 152
" "	June 10, 122	" "	July 22, 114
" "	June 17, 153	" "	July 29, 160
" "	June 24, 166	" "	August 4, 102
" "	July 1, 129	" "	August 11, 104
			Total for 12 weeks, 1657^{cc}

Station 2.—A garden plot between Hillside and Highland avenues, Huntington, about 3^{km} east of the standard. Conditions similar to those at the Carnegie garden, except the elevation, which is about

40^{m} above sea-level. Both this station and the standard were bare of vegetation at the time these comparative readings were made.

	June 5–10	June 10–19	June 19–24	Total (19 days)
Amt. evaporation, Station 2....	90.3^{cc}	145.5^{cc}	100.3^{cc}	336.1^{cc}
Amt. evaporation, standard....	102.2	207.3	112.6	422.1
Comparative evaporation..	88.3%	70.1%	89%	79.6%

This result indicates that for this nineteen-day period the increased elevation is correlated with decreased evaporation. This was quite unexpected, but on account of the small number of instruments at

FIG. 3.—View from Station 1 across the Carnegie garden and salt marsh.

my disposal could not be tested further. The instrument used was subsequently tested and found to be perfectly standardized, so that there is no question about the correctness of this series of readings.

Station 3.—Gravel slide near St. John's Episcopal Church, about 0.25^{km} from the standard. The soil is a coarse sand and gravel; slopes eastward at an angle of 35°; altitude of station 25^{m}. The northern two-thirds of the gravel slide has been so recently disturbed by the removal of gravel, that it is free of vegetation except for some half-dead young trees which have fallen from above part way down the slope. There were none of these near the instrument. The southern third of the slide had been invaded by plants and had become

more or less stable. The vaporimeter was placed on the border between these two areas.

Growing near the instrument were the following plants in very open association: *Polytrichum* sp.? *Androgopon scoparius*, *Deschampsia flexuosa*, *Comptonia peregrina*, *Ionactis linearifolia*, *Baptisia tinctoria*, *Epigaea repens*, and *Vaccinium pennsylvanicum*.

FIG. 4.—Station 4; partially invaded gravel slide.

	June 28–July 1	July 1–8	July 8–14	Total (16 days)
Amt. evaporation, Station 3....	34.0^{cc}	140.3^{cc}	145.6^{cc}	319.9^{cc}
Amt. evaporation, standard....	34.3	151.5	131.5	317.3
Comparative evaporation..	99.1%	92.6%	110.7%	100.8%

The bare gravel slide therefore shows an evaporation approximating that of the standard. As shown by synchronous temperature records, the surface on sunshiny days rises 20° above that of the garden, but the corresponding increase in evaporation seems to be largely compensated by the somewhat lower night rate. This gravel slide station represents the pioneer stage in the reforestation of a

denuded area, and these percentages have a larger interest when compared with the stations representing later stages in this process.

FIG. 5.—Station 5; open forest on top of moraine.

Station 4.—Partly forested gravel slide (*fig. 4*) along the abandoned railroad grade midway between Wolfert and Tramp ponds. It is 2^{km} distant from Station 1; altitude 55^{m}; slopes south at an angle of about 30°. Scrub forest vegetation has invaded this slope and formed

an open association. The principal trees (mostly under 7^{m} in height) are *Pinus rigida*, *Quercus coccinea*, *Q. marylandica*, *Q. prinus*, and *Castanea dentata*. The scattered low growth consists of *Pteridium aquilinum*, *Gaylussacia resinosa*, *Vaccinium pennsylvanicum*, *Myrica carolinensis*, and *Baptisia tinctoria*. The vaporimeter was placed in the partial shade of a pine tree, surrounded by a low clump of huckleberry. Readings were made during the same periods as at Station 3.

FIG. 6.—Typical mesophytic forest with abundant undergrowth, similar to Station 6.

	June 28–July 1	July 1–8	July 8–14	Total (16 days)
Amt. evaporation, Station 4....	14.3^{cc}	103.4^{cc}	72.3^{cc}	190.0^{cc}
Amt. evaporation, standard....	34.3	151.5	131.5	317.3
Comparative evaporation..	41.6%	68.2%	54.9%	59.5%

Since the slope is more toward the south than at Station 3, one might expect a greater evaporation rate, other conditions being equal. But the results indicate that in spite of direction of slope, the partial invasion of the gravel slide by vegetation has produced a 40 per cent. reduction in the evaporation.

Station 5.—Forest on top of moraine directly west of Station 1; altitude 43^{m}. This wood (*fig. 5*) is composed of *Quercus prinus*, *Q. velutina*, *Q. alba*, *Fagus americana*, *Castanea dentata*, *Betula lenta*, *Hicoria glabra*, and *Acer rubrum*. The trees attain a height of 20^{m}.

Nearly all of the undergrowth has been removed and the forest cover is not dense.

	July 15–23 (8 days)
Amt. evaporation, Station 5	71.6^{cc}
Amt. evaporation, standard	136.9
Comparative evaporation	52.2%

When this record is compared with that of Station 4, we see that the further development of the trees to true forest proportions reduces the evaporation near the soil by an additional 10 per cent.

Station 6.—Forest on the Joshua Jones farm along the "short road" to Huntington, 0.5^{km} east of the Carnegie garden. The land slopes gently to the northwest; altitude 50^{m}.

This is a fine example of the dominant forest of the region (*fig. 6*). The principal trees are *Quercus prinus*, *Q. velutina*, *Castanea dentata*, *Acer rubrum*, *Betula lenta*, and *Fagus americana*. The shrub layer is dominated by *Kalmia latifolia*, tree seedlings, *Sassafras sassafras*, *Azalea nudiflora*, *Viburnum acerifolium*, *Cornus alternifolius*, and *C. florida*. The herbaceous plants are *Chimaphila maculata*, *Dryopteris acrostichoides*, *Galium circaezans*, *Aster cordifolius*, *Leptorchis liliifolia*, *Peramium pubescens*, and *Phegopteris*.

	June 5–10	June 10–19	June 19–24	June 24–July 2	Total (27 days)
Amt. evaporation, Station 6	49.3^{cc}	92.1^{cc}	37.6^{cc}	50.0^{cc}	229.0^{cc}
Amt. evaporation, standard	102.2	207.3	112.6	148.8	570.9
Comparative evaporation	48.2%	44.4%	33.4%	33.6%	40.1%

The important difference between this station and the last is the increased undergrowth. When the record was started the trees were just beginning to leaf out. The effect of the increased shade and interference with air movements is well shown in the 15 per cent. reduction in evaporation between the first and last part of the record. When this record is compared with others, it must be on the basis of the last two weeks. It will be noted then that as reforestation proceeds in this region, the evaporation in the lower stratum of the forest decreases from 100 per cent. to about 33 per cent. when the climax forest type is reached.

Station 7.—Ravine forest just south of the "North lot" of the Carnegie Institution, about 0.5^{km} west of Station 1; altitude 10^{m};

soil surface slopes gradually to the northeast. This area is densely wooded and the herbaceous vegetation is very characteristic for the habitat. The trees are *Castanea dentata*, *Fraxinus americana*, *Prunus serotina*, *Betula lenta*, *Acer rubrum*, *Quercus prinus*, and *Tilia americana*. The shrub layer is made up of *Benzoin benzoin*, *Cornus florida*, *Rhus radicans*, *Viburnum acerifolium*, *Smilax rotundifolia*, and *S. herbacea*. The dominant herbs are *Washingtonia longistylis*, *Arisaema triphyllum*, *Trillium cernuum*, *Smilacina racemosa*, *Actaea*

FIG. 7.—Northern edge of swamp forest in which Station 8 was located.

alba, *Impatiens biflora*, *Dryopteris acrostichoides*, and *Sericocarpus asteroides*.

	July 14–23 (9 days)
Amt. evaporation, Station 7	18.5^{cc}
Amt. evaporation, standard	141.9
Comparative evaporation	13.0%

Here we see a further marked reduction in the evaporation rate, when compared with the wooded hilltop and slopes. The presence of Benzoin, Trillium, and Arisaema, however, is in keeping with it.

Station 8.—Swamp forest at the head of St. John's pond, 0.5^{km} from the Carnegie garden (*fig. 7*); altitude 5^{m}. The soil is gravel and the water table is very near the surface. The forest cover is com-

posed of *Quercus alba, Nyssa sylvatica, Liriodendron tulipifera, Fraxinus americana.* The dense shrub layer is dominated by *Hamamelis virginiana, Viburnum molle, Azalea viscosa, Clethra alnifolia, Alnus incana, Smilax rotundifolia, Rhus radicans, Benzoin benzoin,* and *Xolisma ligustrina.* The herbaceous layer contains *Osmunda cinnamomea, Spathyaema foetida, Viola cucullata, Trillium cernuum, Dryopteris noveboracensis, Arisaema triphyllum, Carex crinita, C. Asa-Grayi, Veratum viride,* etc.

	June 10–19	June 19–24	June 24–28	Total (18 days)
Amt. evaporation, Station 8....	20.2^{cc}	11.3^{cc}	9.5^{cc}	41.0^{cc}
Amt. evaporation, standard....	207.3	112.6	94.7	414.6
Comparative evaporation..	9.7%	10.0%	10.0%	9.9%

This record seemed very surprising at first, but as the records from the other habitats increased, it proved to be entirely in harmony with them. During the preceding summer I took some comparative temperature and relative humidity readings for this station and the Carnegie garden. Though the temperatures ran somewhat lower and the relative humidity higher, one would scarcely have predicted an evaporation difference of 90 per cent. for the lower stratum of the two stations. The failure to take into account the relative air movements in the two situations is the probable cause of the apparent discrepancy; but the comparison helps to emphasize the importance and efficiency of the porous-cup vaporimeter as a means of differentiating habitats.

Station 9.—Upper beach area, on "East Beach," 3^{km} north of Northport; altitude 4^{m}. This area is generally considered, on the basis of the vegetation, the most xerophytic along the Sound in the vicinity of Cold Spring Harbor. The direct distance from the Carnegie garden is 12^{km}. The vegetation is dominated by *Ammophila arundinacea, Rosa humilis, Panicum amarum, Lechea maritima, Artemisia caudata, Chrysopsis falcata, Polygonella articulata, Solidago sempervirens, Hudsonia tomentosa,* and *Opuntia opuntia.* The vaporimeter was placed among some shoots of *Rosa humilis,* just sufficiently screened so as not to attract attention. The coarse sandy substratum slopes gradually to the south at this point.

	June 27–July 19 (22 days)
Amt. evaporation, Station 9..........	332.1^{cc}
Amt. evaporation, standard...........	424.3
Comparative evaporation.........	78.2%

Station 10.—Upper beach on "Sand Spit" in Cold Spring Harbor, 1^{km} north of the Carnegie garden; altitude 3^{m}. The instrument was placed near the middle of the spit in the zone dominated by *Ammophila arundinacea.* Other near-by plants are *Solidago sempervirens, Cakile edentula, Asparagus officinalis, Euphorbia polygonifolia, Xanthium canadense, Cyperus Grayi, Polygonella articulata,* and *Verbascum thapsus.*

	July 2–8	July 8–15	Total (13 days)
Amt. evaporation, Station 10..........	112.9^{cc}	138.2^{cc}	251.1^{cc}
Amt. evaporation, standard...........	131.5	151.9	283.4
Comparative evaporation.........	85.8%	90.9%	88.6%

It will be noted that at both Stations 9 and 10 the evaporation is less than at the garden, in spite of the very xerophytic nature of the vegetation. I was unable to analyze this result further with the instruments and time at my disposal. It seems likely that the explanation lies in the low rate of evaporation during the night, due to low temperatures and increased humidity. They are more exposed to the temperature effects produced by the cooler water brought in at the flow of the tides and are more subject to fogs. The correctness of this suggestion can be tested only by an instrument which will record at hourly intervals. It is probable that the evaporation is higher on the beaches during periods of bright sunshine.

Station 11.—Salt marsh adjoining the garden of the Carnegie Institution. The vaporimeter was set up near the outer end of the middle line of the salt marsh (*fig. 8*). As this area is covered by water at extreme spring tides, the instrument was necessarily raised about 5^{dm} above the ground. The jar was protected from the sun by a heavy wrapping of felt paper. From the standpoint of the marsh vegetation the instrument stood on the tension line between the *Spartina polystachya* association and the zone dominated by *S. patens.* Other plants occurring near this point are *Atriplex hastata, A. arenaria, Tissa marina, Salicornia Bigelovii, Plantago maritima,* and *Limonium carolinianum.*

	June 14–23	Aug. 5–12	Total (14 days)
Amt. evaporation, Station 11..........	175.2^{cc}	171.2^{cc}	346.4^{cc}
Amt. evaporation, standard...........	141.9	129.7	271.6
Comparative evaporation.........	123.4%	131.9%	127.5%

It is here then that the greatest evaporation rate for this vicinity

was recorded. This relation was not wholly unexpected, as high temperatures and low relative humidities had been found to occur here during the preceding summer; but the amount of the excess seemed large. Preceding the second attempt at measuring this rate, all of the instruments were brought to the garden and exposed side by side for four days. Their individual factors were recalculated and found to be practically the same as those calculated by LIVINGSTON. Further,

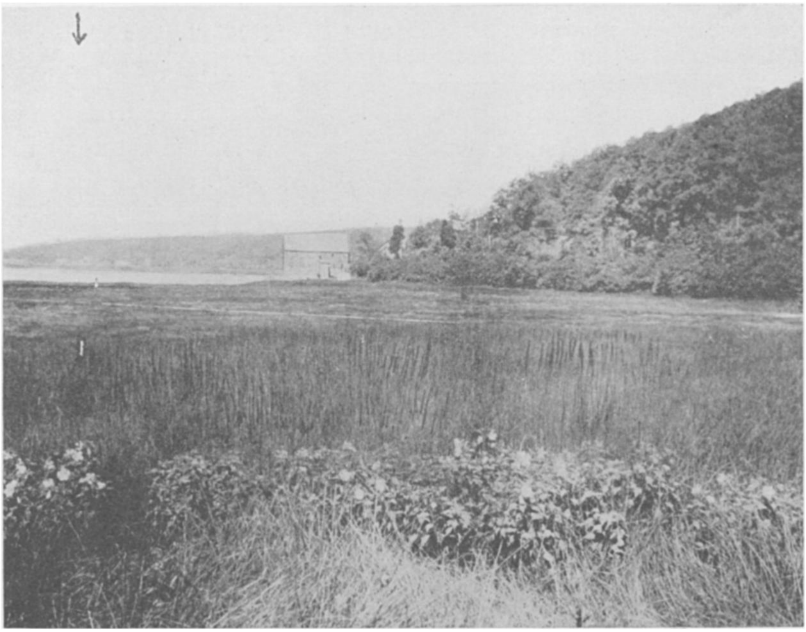

FIG. 8.—View north from road across the salt marsh; Station 11 in the distance; Station 12 at the left.

a different instrument was used for the second period. Just how this increased evaporation over the salt marsh may be accounted for is not clear. The suggestion is offered that the deposition of salt on the vegetation is effective in reducing the vapor tension of the overlying stratum of air sufficiently to raise the evaporation rate.

Station 12.—Inner end of salt marsh, on the tension line between the *Spartina patens–Juncus Gerardi* association and the *Scirpus americana* association (*fig. 7*). Although the tide occasionally invades this

area, the water proved by chemical test to be without a trace of chlorid at the next low tide. The vaporimeter was set up precisely as at Station 11.

	Aug. 5–13 (8 days)
Amt. evaporation, Station 12	112.8^{cc}
Amt. evaporation, standard	129.7
Comparative evaporation	86.9%

It might be urged, in connection with the high percentage reading at Station 11, that the result was due to the elevation of the instrument. This cannot be offered, however, as an explanation of the great difference between Stations 11 and 12.

The other species of plants found near the station are *Eleocharis rostellata*, *Asclepias pulchra*, *Carex gracilis*, *Lysimachia terrestris*, *Eupatorium perfoliatum*, *Hibiscus moscheutos*, and *Dryopteris thelypteris*.

Station 13.—Fresh-water marsh—a continuation of the same marsh in which the two preceding stations were located. A road, elevated about 3^{m} above the marsh, separates this station from the last. I have no doubt but that this road interferes somewhat with the normal air drainage in its vicinity and may account in part for the low reading at Station 13. This station is sufficiently elevated to be beyond the reach of the highest tides. The vegetation about the instrument consisted of *Onoclea sensibilis*, *Lysimachia terrestris*, *Juncus effusus*, *Dryopteris thelypteris*, *Lycopus americana*, *Iris versicolor*, *Epilobium adenocaulon*, *Asclepias pulchra*, *Carex hystricina*. Near by grew *Acorus calamus*, *Eupatorium perfoliatum*, *Impatiens biflora*, *Ilysanthes attenuata*, *Rumex altissimus*, *Polygonum sagittatum*, *Scirpus americana*, *Myrica carolinensis*, etc.

	Aug. 5–13 (8 days)
Amt. evaporation, Station 13	57.0^{cc}
Amt. evaporation, standard	129.7
Comparative evaporation	43.9%

When we compare this record with those obtained simultaneously at the last two stations, we see that there is a further decrease of 40 per cent. as we go farther away from the outer salt marsh. Even making allowances for the interference with air currents at this station, there would be a well-marked decrease in this direction.

Putting these three station records and the standard together we see that as we go west from the middle outer portion of the salt marsh into the garden, the rate decreases by a fourth. As we go south to the edge of the salt marsh the rate is decreased nearly a half, and when the middle of the fresh-water marsh is reached the rate has decreased to one-third.

GENERAL CONCLUSIONS

From the foregoing data, meager as they are, it is evident that we have in the porous-cup vaporimeter an instrument that will be of the greatest importance in the study of habitat conditions. Unlike so many of the recently exploited forms of instruments, it furnishes data that may be directly related to the plant. It has the great advantage over readings made from open water surfaces, in that the surface is constant and is continually exposed in the same way. Comparative readings may be obtained from different habitats by first standardizing the instruments.

The principal objection to the porous cup is its inability to withstand frost; this makes it useless in winter and early spring; it also limits its use at high elevations. Its usefulness might be greatly increased by making it self-recording, so that the diurnal variations could be accurately obtained.

The data which my observations furnish are of course characteristic only of the stratum within a meter of the soil surface. In the forest as we go from soil to tree-top this relative evaporation must increase; but it is in the lowest stratum that the seedlings, which are to determine the future of the area, have their struggle with the environment. With these data in hand it is not difficult to see why seedlings of Trillium, Arisaema, and Veratrum are successful in the swamp forest with its 10 per cent. relative evaporation; why they fail in the open hillside forest with its 50 per cent. rate; and why they are never seen on the near-by gravel slide with its relative rate of 100 per cent. in addition to its unstable character.

The following diagram (*fig. 9*) shows in a more graphic way the comparative rates of evaporation in the lowest stratum of the common habitats about Cold Spring Harbor.

In the reforestation of the gravel slides in this locality it will be seen that the greatest decrease in the demands for transpiration on the

part of seedlings takes place during the first stages. This greatly aids in accounting for the well-known fact that the development toward a closed association proceeds with such increasing rapidity when once a few plants gain a foothold. Attention has been frequently called to the importance of pioneers as shade-producers, while their effectiveness in reducing transpiration has been underestimated.

The fact that the weekly evaporation rate for a beach covered with xerophytes should be less than that for a garden may seem anomalous. But when the diminished ground-water supply, the sterility of the soil, and the probable high rate of evaporation during short periods are

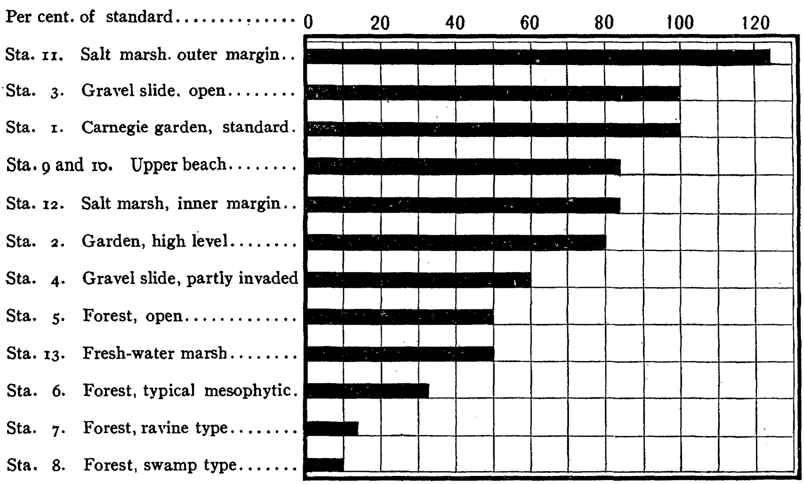

FIG. 9.—Diagram showing comparative evaporation rate in the lowest stratum of the several plant societies.

taken into account, the elimination of more mesophytic species is not surprising.

In the case of the high-level and low-level gardens further observations may alter these relative figures.

The high rate of evaporation in the salt marsh helps in the understanding of the structure of these plants.

Further work upon the rate of evaporation at different levels within the forest will aid greatly in estimating the factors involved in competition between trees. For a complete understanding of habitat conditions in general it seems essential that an instrument which will record the losses for smaller time intervals be devised.

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